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ADVANCED ACOUSTIC IMAGING WITH LINEAR TRANSDUCER ARRAYS.(U)
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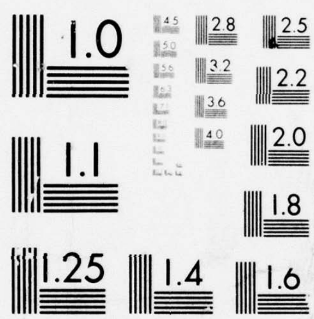

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ADVANCED ACOUSTIC IMAGING WITH LINEAR TRANSDUCER ARRAYS

JAMES M. SMITH
MATERIALS TESTING TECHNOLOGY DIVISION

December 1977

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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ABSTRACT

A prototype ultrasonic inspection system, using a sequentially fired transducer array, has been built that is much faster than conventional single-element transducer systems. This system was assembled with off-the-shelf components and would appear to be an attractive solution to nondestructive testing problems that require fast inspection rates and have resolution and sensitivity requirements that are consistent with the use of unfocused transducer elements. The fast inspection of a number of Army components, such as artillery projectile rotating bands and tank track pads, has been demonstrated with this system.

INTRODUCTION

In the last few years there has been a growing interest in the development of ultrasonic inspection systems that are capable of high inspection rates. Within the Army there is a strong need for fast ultrasonic inspection systems for large-caliber projectiles, for gun tubes, and for a number of other products that must be tested in large numbers. In many cases, the required inspection rate cannot be achieved by the use of conventional single-element transducers, and new techniques are needed. This paper will discuss the development of a prototype ultrasonic inspection system that is almost two orders of magnitude faster than conventional techniques. The reduction in testing time is achieved by using a linear array of piezoelectric elements that are sequentially excited in a pulse-echo fashion.

PRINCIPLES OF OPERATION

The heart of the AMMRC acoustical imaging system is a pulser-receiver, built by the Advanced Diagnostic Research Corporation,* that sequentially excites a 64-element piezoelectric transducer array. This instrument became available commercially about three years ago and was originally designed to give physicians a real-time B-scan[1] display primarily of the abdominal region. It has been a valuable tool for the study of fetal activity in pregnant women. It became apparent to AMMRC that this unit could be successfully applied to nondestructive testing applications in a much more useful C-scan[1] format if the ultrasonic data were processed and displayed differently. The simplified block diagram shown in Figure 1 illustrates the approach that was taken to adapt the ADR instrument to nondestructive testing applications.

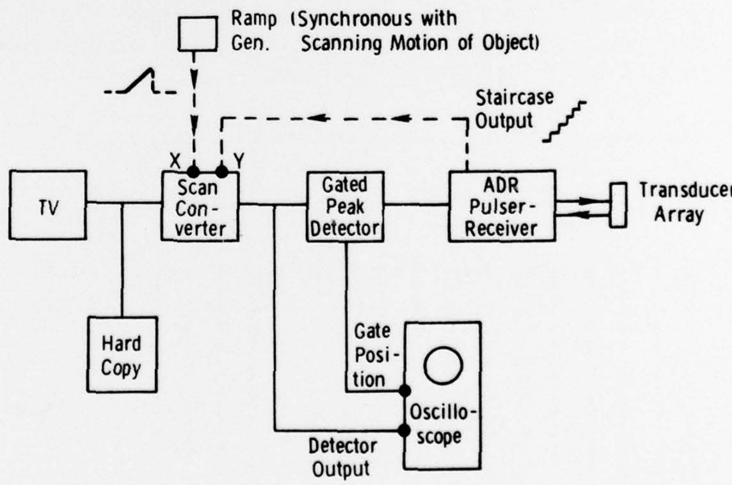

Figure 1. Block diagram of AMMRC array imaging system.

*Advanced Diagnostic Research Corporation, 2202 South Priest Drive, Tempe, Arizona 85282.

1. SMITH, J. *A Survey of Advanced Techniques for Acoustic Imaging.* Army Materials and Mechanics Research Center, AMMRC MS 77-7, August 1977.

The operation of this system begins with the pulser-receiver and the transducer array. The ADR pulser-receiver, which operates in a pulse-echo mode, excites four adjacent transducer elements at one time and then listens for the returned echoes before the next set of four elements is fired. For example, in Figure 2, the first four elements (1, 2, 3, 4) are excited; then elements 2, 3, 4, 5; then 3, 4, 5, 6, and so on until all of the 64 elements in the array have been fired in this fashion. It takes 1/40 of a second to sweep across the entire array in the above manner, which corresponds then to the time required to generate one line of information of a C-scan. A complete C-scan image is formed by moving the array or the object along a line perpendicular to the axis of the array, or for the case of a cylindrical symmetric object, by rotating the object through 360 degrees.

The ultrasonic echoes, received by each set of four transducer elements, are time gated, peak detected, and then stored in a scan converter, which is a fast analog image storage device. The timing requirements for the gated peak detector and the scan converter are accomplished by driving these instruments synchronous with the ADR pulser-receiver. The essential feature of the scan converter is a storage tube that stores, in the form of a charge pattern on a silicon target, the amplitude and position (X and Y inputs) of the defect indications. The Y input to the scan converter is the staircase output from the ADR instrument which tells the converter which set of transducer elements is being fired. The X input is a signal that corresponds to the scanning motion of the test object.

At the completion of the scan, which generally takes only a few seconds, a C-scan of the test object has been stored in the scan converter. This information is then read into a TV monitor or into a hard copy unit which produces a permanent gray scale record on an 8-1/2 x 11-inch sheet of paper. Therefore, the scan converter, the TV monitor, and the hard copy unit replace the conventional wet or dry paper recorders which are incapable of high-speed writing.

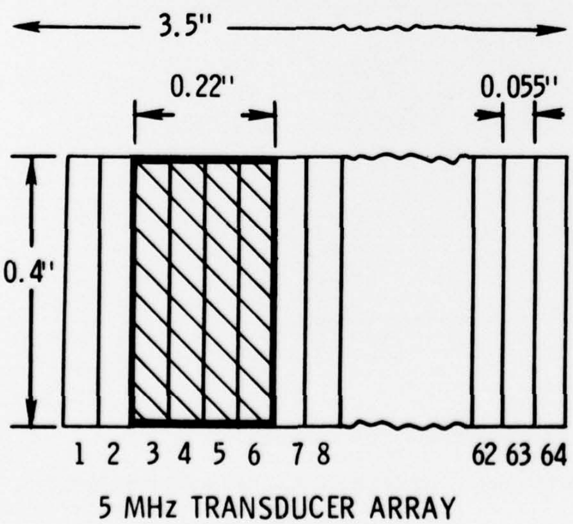

Figure 2. Diagram of ADR transducer array.

EXPERIMENTAL RESULTS

Rotating Band Inspection

The fast inspection of brazed and welded overlay copper rotating bands bonded to 8-inch artillery shell motor bodies has been demonstrated at AMMRC. The problem is one of determining whether the band is adequately bonded to the motor body. The motor body is placed on a small turntable and the transducer array is positioned inside the shell with the axis of the array pointed in the vertical direction, as shown in Figure 3. Only one full rotation of the shell is required to generate a C-scan of the entire rotating band region. This procedure takes less than 10 seconds, which is considerably faster than the time required (3 to 5 minutes) to inspect a band with a conventional single-element transducer.

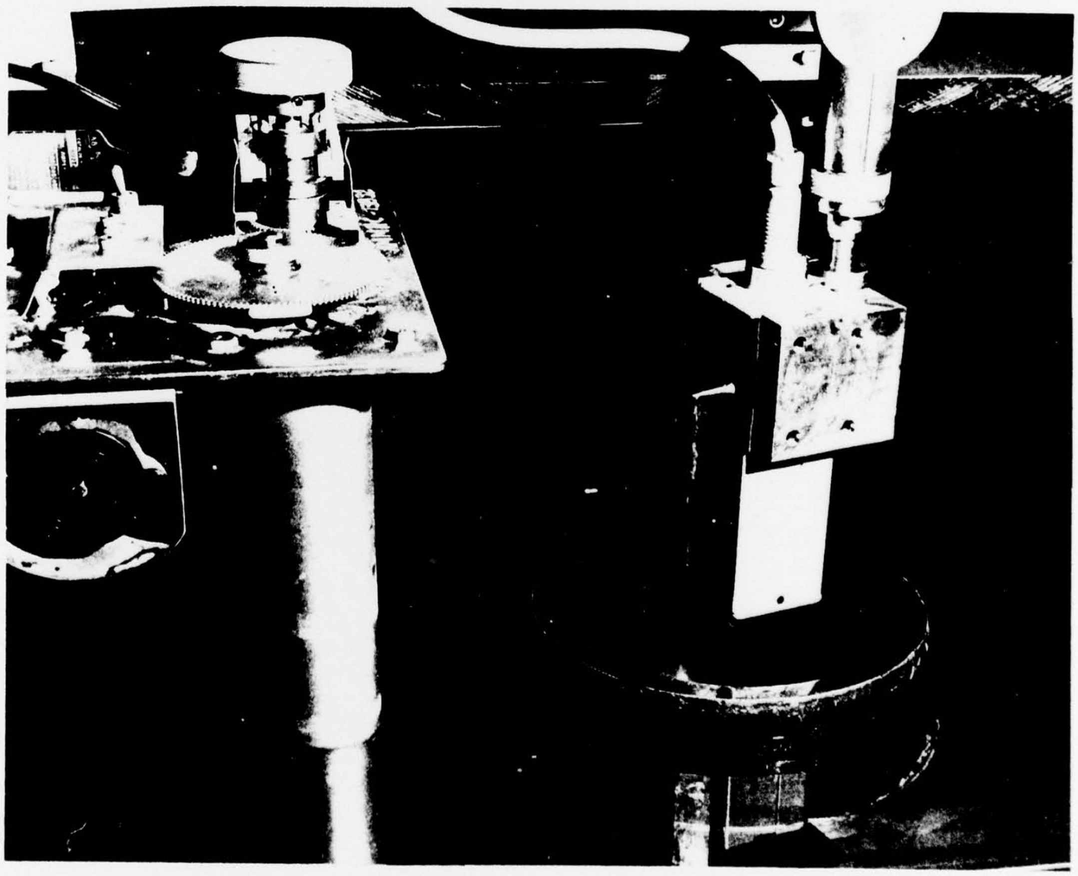

Figure 3. Transducer array and rocket motor body.
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An example of a C-scan produced by the AMMRC system for the band problem is illustrated in Figure 4. This figure shows both a C-scan of a brazed copper band as displayed on the TV monitor and an example of the hard copy produced from the video image. The dark patches on the TV monitor represent unbonded areas between the 8-inch motor body and the rotating band. This particular motor body, which contained intentional unbonded regions produced by placing Grafoil disks between the shell body and the band before the brazing operation, had previously been used as a standard for conventional ultrasonic tests of rotating bands. The C-scan of Figure 4 compares very favorably with the conventional scans as documented in Reference 2.

Figure 4. C-scan of brazed copper band.
19-066-1204/AMC-77

2. HANNON, F. S., BROCKELMAN, R. H., QUIGLEY, J. M., and RODERICK, D. J. *Ultrasonic Inspection of Brazed and Welded Overlay Rotating Band Attachment on Artillery Shells.* Army Materials and Mechanics Research Center, AMMRC TR 76-20, July 1976.

A graphic illustration of the close agreement between conventional C-scans and the array imaging approach, as applied to the rotating band problem, is shown in Figure 5. The top image is a conventional scan of a welded overlay band on an 8-inch rocket motor body, and the lower C-scan was generated by the fast imaging techniques using a 5-MHz transducer array. The five flat bottom holes that were drilled through the band, ranging from 1/8" to 1/4" diameter, are clearly visible in both scans. The long dark region on the left indicates a poorly bonded section of the band that was previously documented in Reference 2.

There is a difference in the two scans of Figure 5 that should be pointed out. The array imaging technique generates a gray scale image in which the gray levels are related to the acoustic echo amplitude. The conventional scan, as presented in Figure 5, does not contain gray scale information. Of course, conventional gray scale techniques are available, but in many NDT ultrasonic instruments the setup time required to adjust the gray scale shading is lengthy. For this reason, a go no-go type of scan with a threshold for writing is often used. In contrast to this, the gray levels of the array imaging system are easy to set because the scan converter has controls for gray scale shading which can be adjusted *after* the ultrasonic data is stored.

An example of this is illustrated in Figure 6 which shows the same C-scan displayed with three different shadings of gray. The projectile was scanned only once and only the relative gray level shadings as viewed on the TV monitor have been changed. The lower image is displayed such that only large acoustic echoes fully darken the TV monitor. In a sense, then, the sensitivity of the visual display has been turned down relative to the above two images. The ability to easily change the gray level is useful for quickly determining the relative amplitude of the defect indications at different locations on the band.

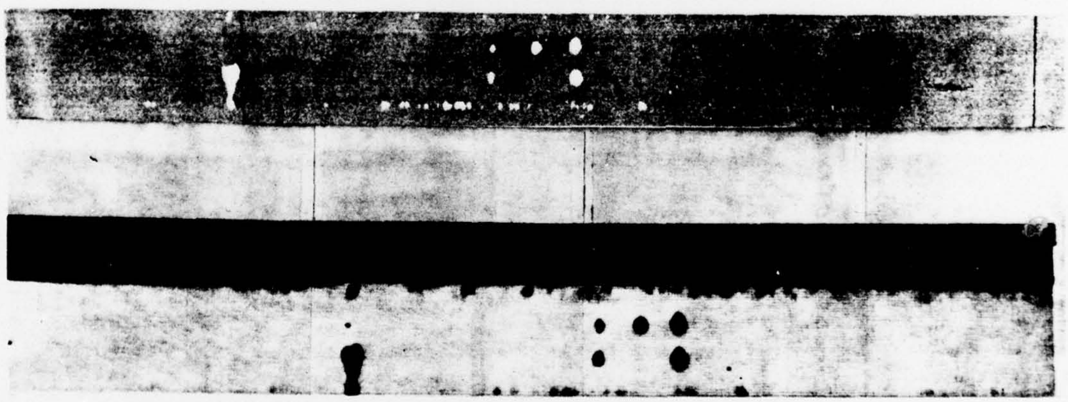

Figure 5. C-scan of a welded overlay rotating band. The top image is a conventional scan, the bottom image was produced with the array imaging techniques.

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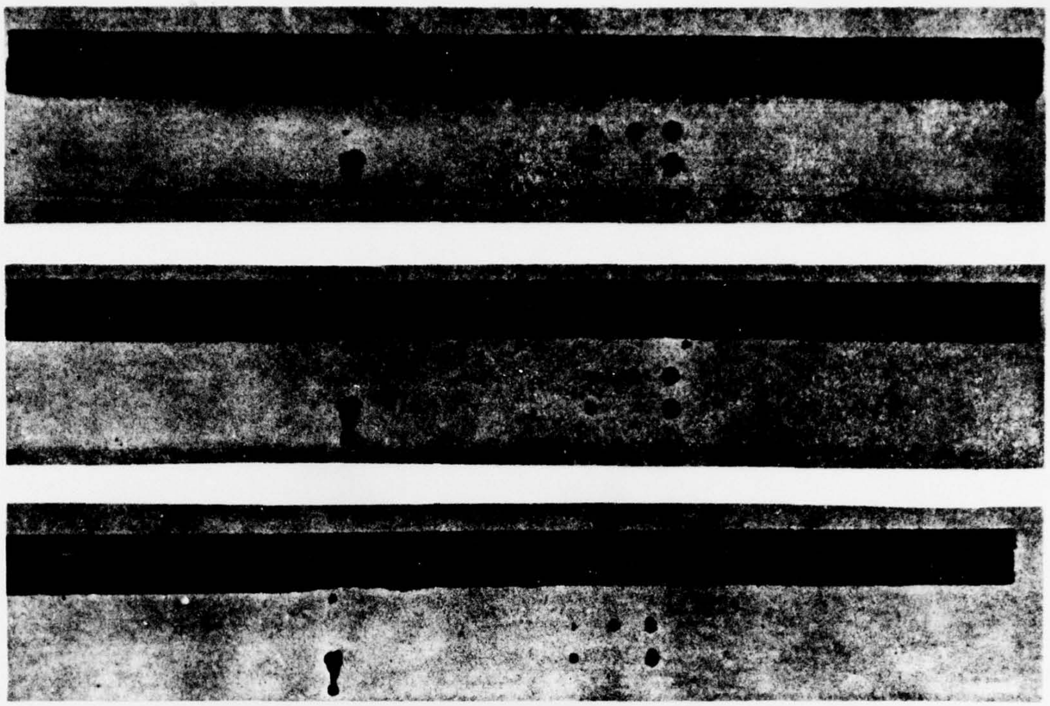

Figure 6. C-scan of a welded overlay bond displayed with three different gray level shadings.
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Another interesting benefit that arises from the use of a scan converter as the image storage medium is the zoom capability of these devices. A particular portion of the C-scan can be enlarged on the TV monitor by as much as a factor of four.

Inspection of Tank Track Pad and Graphite Epoxy Specimen

C-scans of flat shaped objects can be obtained by moving the array along a line perpendicular to the array axis. Except for this difference, the system operates in essentially the same fashion as previously described.

Figure 7 shows a comparison between conventional C-scans (left) and the results produced by the array system (right) for two different items, a tank track pad and a graphite epoxy compact tension specimen. Both the tank track pad and the graphite epoxy specimen were inspected in less than five seconds of actual scanning time using the array imaging approach. For the track pad, the system was set up to find unbonds between the steel and the rubber. In the graphite epoxy specimen, the problem was one of detecting delaminations between the plys. These two examples are interesting because the conventional C-scans were generated using focused 15-MHz

a. Tank Track Pad

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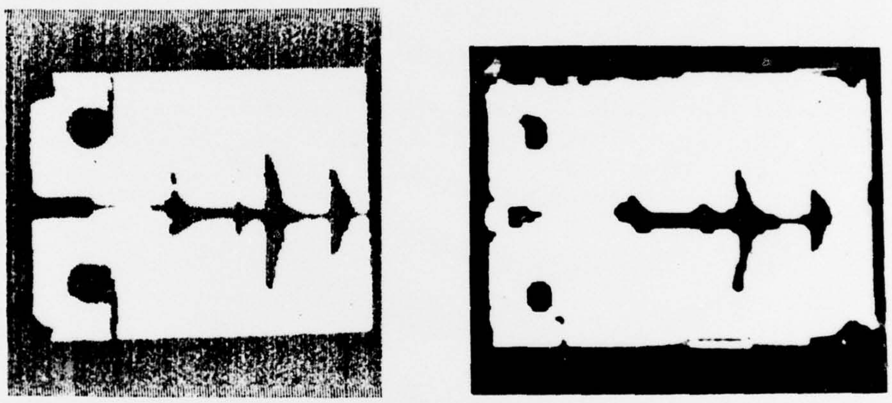

b. Graphite Epoxy Compact Tension Specimen

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Figure 7. Comparison between conventional C-scans (left) and scans produced by the array imaging technique (right).

transducers, but the array imaging was accomplished at lower frequencies (3.5 MHz for the tank track pad and 5 MHz for the graphite epoxy specimen) using array elements that are, of course, unfocused. As expected, there is a decrease in resolution with the unfocused array, but the images are still quite good. This decrease in resolution and sensitivity, which is the result of the use of unfocused transducer elements, is the primary disadvantage of this technique.

CONCLUSIONS

A prototype ultrasonic inspection system, using a sequentially fired transducer array, has been built that is much faster than conventional single-element transducer systems. This system was assembled with off-the-shelf components and would appear to be an attractive solution to nondestructive testing problems that require fast inspection rates and have resolution and sensitivity requirements that are consistent with the use of unfocused transducer elements. Because the essential electronic components used in this system are easily available, the cost of applying this technique to production line testing is not much more than conventional ultrasonic testing.

More complicated array imaging techniques (such as phased arrays) are being developed by other laboratories, and these systems will have improved sensitivity, resolution, and beam steering capability. However, in contrast to the approach described in this paper, practical pulse-echo phased arrays will probably not be technically possible for another three years.

ACKNOWLEDGMENT

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